Development of an Autonomous Broadband Acoustic Scattering System for Remote Characterization of Zooplankton

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LONG-TERM GOALS

The long term goal of this research is to develop autonomous, high-frequency broadband acoustic scattering techniques, appropriate for use on a variety of platforms, including towed, profiled, moored, and mobile platforms that enable the remote characterization of zooplankton distributions on ecologically relevant spatial and temporal scales.

OBJECTIVES

The primary objective of the proposed research is to develop, calibrate, and test an autonomous, compact, low-power, high-frequency broadband acoustic backscattering system for remote characterization of zooplankton distributions.

APPROACH

Over the last 40 years, there has been significant research effort directed towards the use of high-frequency narrowband acoustic scattering techniques to remotely investigate the distribution, abundance, and size of zooplankton on multiple spatial and temporal scales (e.g. Holliday and Pieper, 1980, 1995; Pieper et al., 1990; Napp et al., 1993; Wiebe et al., 1996; Benfield et al., 1998; Brierley et al., 1998; Korneliussen and Ona, 2002; Mair et al., 2005; Trevorrow et al., 2005; Lawson et al., 2006;

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14. ABSTRACT
The long term goal of this research is to develop autonomous, high-frequency broadband acoustic scattering techniques, appropriate for use on a variety of platforms, including towed, profiled, moored, and mobile platforms that enable the remote characterization of zooplankton distributions on ecologically relevant spatial and temporal scales

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Lavery et al., 2007). Acoustic scattering techniques provide a rapid, high-resolution, synoptic, remote sensing tool to compliment more traditional sampling strategies. In fact, some of the world's largest stocks of zooplankton, such as Antarctic Krill (Nicol and Endo, 1999), as well as large fish stocks, are assessed using single- or multi-frequency narrowband acoustic scattering techniques (Simmonds and MacLennan, 2005). Yet reducing the ambiguities in the quantitative interpretation of the acoustic returns remains one of the outstanding challenges.

The development of high-frequency broadband acoustic scattering techniques, spanning multiple octaves of bandwidth, may in principle lead to decreases in the ambiguities associated with interpretation of acoustic scattering measurements of zooplankton. The goal is to capitalize on the different characteristic frequency-dependent spectra associated to different scattering sources. The advantages of using broadband versus narrowband acoustic scattering techniques are generally recognized, supported by laboratory measurements of broadband scattering from zooplankton (e.g. Stanton *et al.*, 1998; Roberts and Jaffe, 2008) and micronekton (e.g. Au and Benoit-Bird, 2008).

The application of high-frequency broadband acoustic scattering techniques in the field has been limited. The few broadband systems that are available commercially are cabled, relatively bulky, and have a restricted frequency range (e.g. EdgeTech < 600 kHz, Lavery et al., 2009; ScanFish 85-155 kHz, Ross and Lawson, 2009). To the best of our knowledge, the only custom-built high-frequency broadband acoustic scattering system that has been built and successfully used for the purpose of investigating fish and zooplankton is a seven-octave-bandwidth hull-mounted system (Foote et al., 2005). In contrast, lower frequency broadband acoustic scattering systems (1-120 kHz) to remotely characterize fish have been used more prevalently (e.g. Holliday, 1972; Thompson and Love, 1996; Zakharia et al., 1996; Love et al., 2004; Stanton et al., 2009).

In addition, there are no published studies on the development of high-frequency broadband acoustic scattering systems suitable for use on autonomous vehicles, such as gliders and AUVs, which offer advantages in persistence and spatial coverage. Although many autonomous vehicles carry an ADCP, which provides a crude measure of a backscatter at a single narrowband frequency, and some AUVs carry single-frequency sidescan sonars (and this technology has been adapted for gliders), the lack of suitable instrumentation has impeded the use of broadband techniques from these platforms.

The autonomous broadband system currently under development at WHOI should be ideally suited for deployment on small mobile platforms (as well as moored, profiling, or towed applications). There are two key issues to address: miniaturization and bandwidth. The approach taken here is to develop a compact, fully-programmable, low-cost, low-power, autonomous, high-frequency broadband acoustic scattering system by adapting existing technology recently developed at WHOI for a monostatic Doppler sonar module. Key personnel for this project include: Andone Lavery as the PI for this project and who has overall responsibility for the successful development, testing, and calibration of the broadband system. Gene Terray, who developed the original sonar Doppler sonar boards and is responsible for oversight of the modifications to these boards. Fred Jaffre is responsible for the "nuts and bolts" of the modifications to the sonar boards, integration of the broadband transducers, software development, and overall system performance. Malinda Sutor is responsible for interpreting the field data in terms of the biological groundtruthing.

WORK COMPLETED

A. System development: first-generation system

An autonomous high-frequency broadband acoustic backscattering system has been developed, based on a monostatic Doppler sonar module recently developed at WHOI for turbulence studies by E. Terray and T. Austin with NSF support. The system has the capability of spanning the frequency range from 100 kHz to 20 MHz. The original sonar module was not optimized for measurements of acoustic backscatter, as Doppler shift can be estimated without using the signal amplitude. However, the receiver is linear, and the received signal is digitized at 20 MHz, and both the transmitter and receiver electronics (downstream of the preamplifier) are fully digital. Relatively straightforward modifications were necessary to allow backscattering to be measured. These modified sonar boards (revision 1) constitute the core of the first-generation autonomous broadband acoustic backscattering system. Each rev 1 sonar module has 16 GB of on-board flash memory, and is low-power, using approximately 1.5 Watts. Each sonar board is 1.25 inches in width and 5.25 inches long. A compact underwater housing has been fabricated, measuring 4 inches in diameter and 9 inches in length to house three such boards, depth rated to 500 m. Initial laboratory testing, calibrations and field tests, have been performed with the first-generation WHOI autonomous broadband acoustic scattering system with rev 1 sonar boards.

B. System development: second-generation system

In parallel to the first-generation system development, a second-revision (rev 2) sonar board was also under development. These new rev 2 sonar boards are slightly larger, measuring 2 inches in width and 5.25 inches in length, resulting in the need for a new, slightly larger diameter underwater housing, measuring 5 inches in diameter and 9 inches in length, depth rated to 500 m. Benefits of the rev 2 boards include:

1. 2MB of RAM. The extra memory translates into longer signals, up to 43ms in length, corresponding to 145 times the maximum signal length of 300μs using the rev1 boards. This capability should improve signal-to-noise ratios, after pulse compression processing, which are approximately given by the product of the signal duration and bandwidth.

2. USB2.0 for faster data downloading. A USB extender will be placed in the housing in order to have up to 20m of data cable. In addition, it will be possible to download the data from one SD card while pinging and logging new data on the other SD card.

3. Two 32GB SD cards for memory storage, versus one 16GB SD card. This allows longer deployments as well as real-time data downloading.

4. 4 independent receive channels versus 1 receive channel on the rev1 board. This capability is not being immediately capitalized on, but future applications of this may include measurements of the angular dependence of scattering.

5. Embedded sensors (thermometer, accelerometer, input for external pressure sensor and compass).

6. A more robust transmitter with bigger transistors, resulting in more available energy to transmit longer and stronger signals. Trade-offs between improved signal-to-noise and power consumption are being assessed.

Work is currently under way to integrate the rev 2 sonar boards with the broadband transducers.

C. Broadband transducers
Initially, three rev 1 boards were modified and interfaced with three almost octave-bandwidth transducers with center frequencies at 200 kHz (Airmar, approx. 9 degrees beamwidth at center frequency), 500 kHz (Airmar, custom-made, approx. 3 degrees beamwidth at center frequency), and 1 MHz (Panametrics, approx. 3 degrees beamwidth at center frequency). During laboratory and field tests of the first-generation system it became apparent that the 200 kHz BB and 1 MHz BB channels suffered from excessive noise. The three main factors contributing to this noise were 1) the impedance mismatch between the transducers and the Doppler sonar board, which had not been optimized, 2) a poor quality transducer at 1 MHz, and 3) broad beamwidth for the 200 kHz BB transducer.

The 200 kHz BB transducer has been replaced by a custom-built almost-octave-bandwidth 160 kHz broadband transducer (Airmar, approx. 6 degrees beamwidth at center frequency). The 1 MHz BB transducer has been replaced with a custom-built almost-octave-bandwidth 1 MHz broadband transducer (Airmar, approx. 3 degrees beamwidth at center frequency). An additional transducer with center frequency at 2 MHz (Reson TC3021, approx. 2 degrees conical beamwidth at center frequency) will also be integrated into the system. The new transducers have been interfaced with the rev 1 boards and tested in the laboratory, and are in the process of being interfaced and tested with the rev 2 boards.

D. Data analysis and software development
Compressed pulse processing techniques have been applied to the broadband data in order to improve the spatial resolution of the measurements as well as to increase the signal-to-noise ratio (Chu and Stanton, 1998). Software has been developed to visualize the acoustic data, for performing multiple-standard target calibrations (Atkins *et al.*, 2008), pulse compression processing, and for spectral analysis of the broadband data.

E. System calibration
The first-generation autonomous broadband acoustic scattering system has been calibrated using a 20mm diameter spherical tungsten carbide standard target. Power linearity and the air-water surface reflection have been measured. The surface reflection provides an almost ideal signal for performing matched filter operations.

F. Field demonstration
The basic function of the first-generation WHOI broadband backscattering system using the rev 1 boards has been tested in the field with the original transducers. The system was deployed from the RV Tioga in the Connecticut River in November 2008, with coincident measurements of turbulence and salinity microstructure. This system was deployed from Rocky Geyer’s MAST (Measurement Array for Sensing Turbulence) in a completely autonomous mode of operation. This field test was heavily leveraged on an existing ONR-funded project.

RESULTS

A first-generation autonomous, compact, high-frequency broadband acoustic scattering system has been developed that employs three broadband transducers spanning the frequency range from 150 kHz to 1250 kHz with some gaps. This system has been calibrated using standard target techniques. Reasonable agreement between the theoretical modal series solution for an elastic sphere and the measured broadband scattering has been obtained in the laboratory (Figure 1). The basic functionality of the system has been demonstrated in the field. It was found that the 500 kHz BB channel of the first-generation system provided good measurements of acoustic backscattering which were highly correlated to salinity microstructure in the CT River (Figure 2). Measurements of acoustic scattering from salinity microstructure using the first-generation WHOI broadband backscattering system agreed favorably to the broadband measurements obtained with the commercial Edgetech system (Figure 2).

High noise levels on two channels of the first-generation system have resulted in the development (currently in the last stages) of a second-generation broadband system as well as the integration of new custom-built broadband transducers, spanning the expanded frequency range from 120 kHz to 24 MHz, with some gaps. After being tested and calibrated in the laboratory, the performance of the second-generation system will be demonstrated in the field by collecting coincident acoustic scattering data, optical video plankton images of zooplankton, and net samples. This field effort is planned for October 2009.

IMPACT/APPLICATIONS

The goal of this project is to produce a compact, autonomous, high-frequency broadband acoustic backscattering system suitable for use on small mobile platforms, thus providing a new and unique capability for the acoustic sensing of zooplankton distributions. Once developed, this system will:

1. Provide the zooplankton bioacoustics community with access to a low-cost, autonomous, compact, broadband, high-frequency, acoustic backscattering system that has the potential to significantly reduce the well-known ambiguities in estimating biologically meaningful parameters associated to the interpretation of traditional single-frequency acoustic backscattering measurements. (A sonar module, with transducer, can be fabricated for under $2k.)

2. The work proposed here will significantly enhance the capabilities of gliders and small AUVs for mapping zooplankton distributions on ecologically relevant scales, with, for example, direct application to mapping the prey field of zooplanktivorous whales. In addition, this system could easily be used as a surface or bottom tracking device.

RELATED PROJECTS

"High-Frequency Broadband Acoustic Scattering from Temperature and Salinity Microstructure: From Non-Linear Internal Waves to Estuarine Plumes," Lavery, A.C. Funded by ONR Ocean Acoustics. A cabled, high-frequency (150-600 kHz) broadband acoustic scattering system developed by Edgetech was used to measure acoustic scattering from nonlinear internal waves during SW06.

"Remote Sensing of Temperature and Salinity Microstructure in Rivers and Estuaries Using Broadband Acoustic Scattering Techniques," Lavery, A.C., Terray, E., and Gallager, S. Funded by ONR Physical Oceanography. Broadband acoustic scattering from temperature and salinity microstructure has been measured in the Connecticut River.

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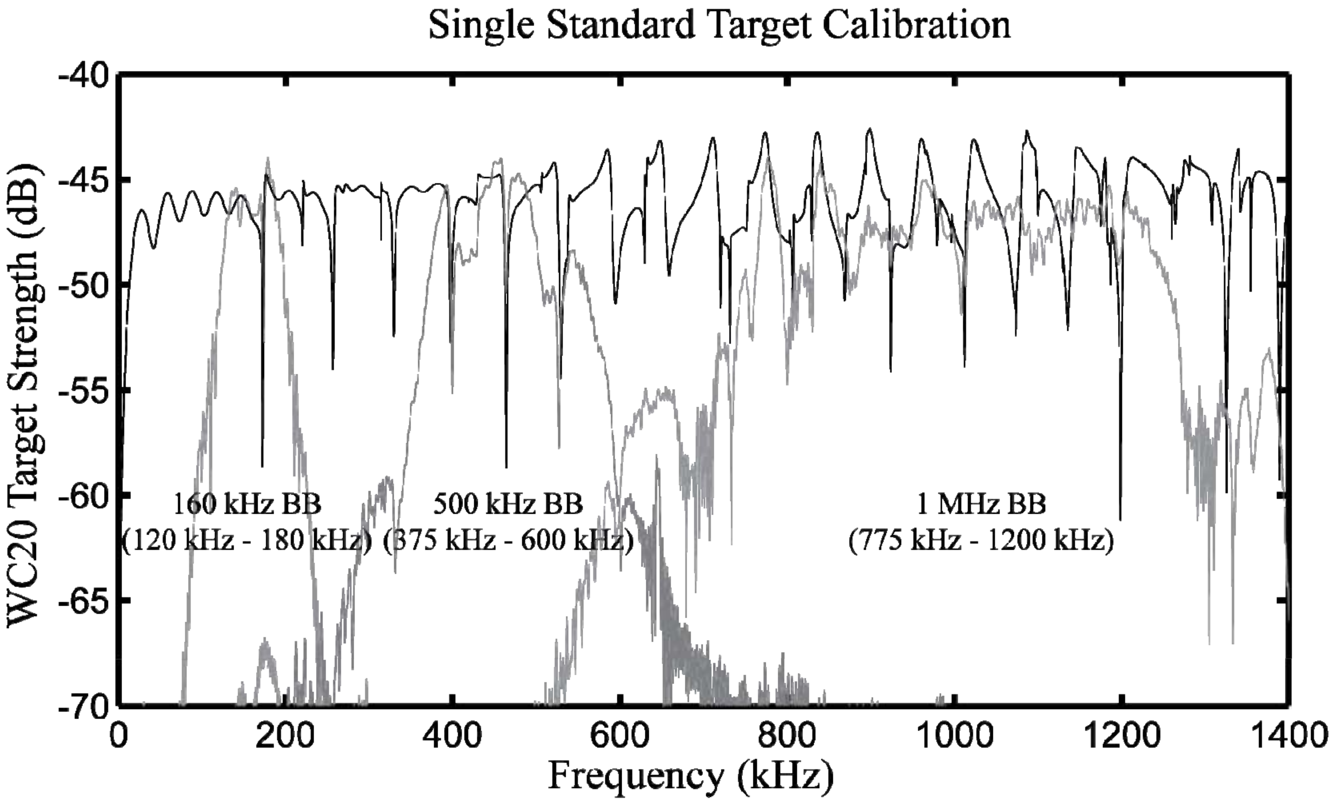

Figure 1. Comparison of the theoretical scattering prediction for a 20mm diameter spherical tungsten carbide standard target, based on the modal series solution, to the measured scattering using the first-generation WHOI autonomous broadband acoustic scattering system for the custom-built 160 kHz, 500 kHz, and 1 MHz almost-octave-bandwidth Airmar broadband transducers.

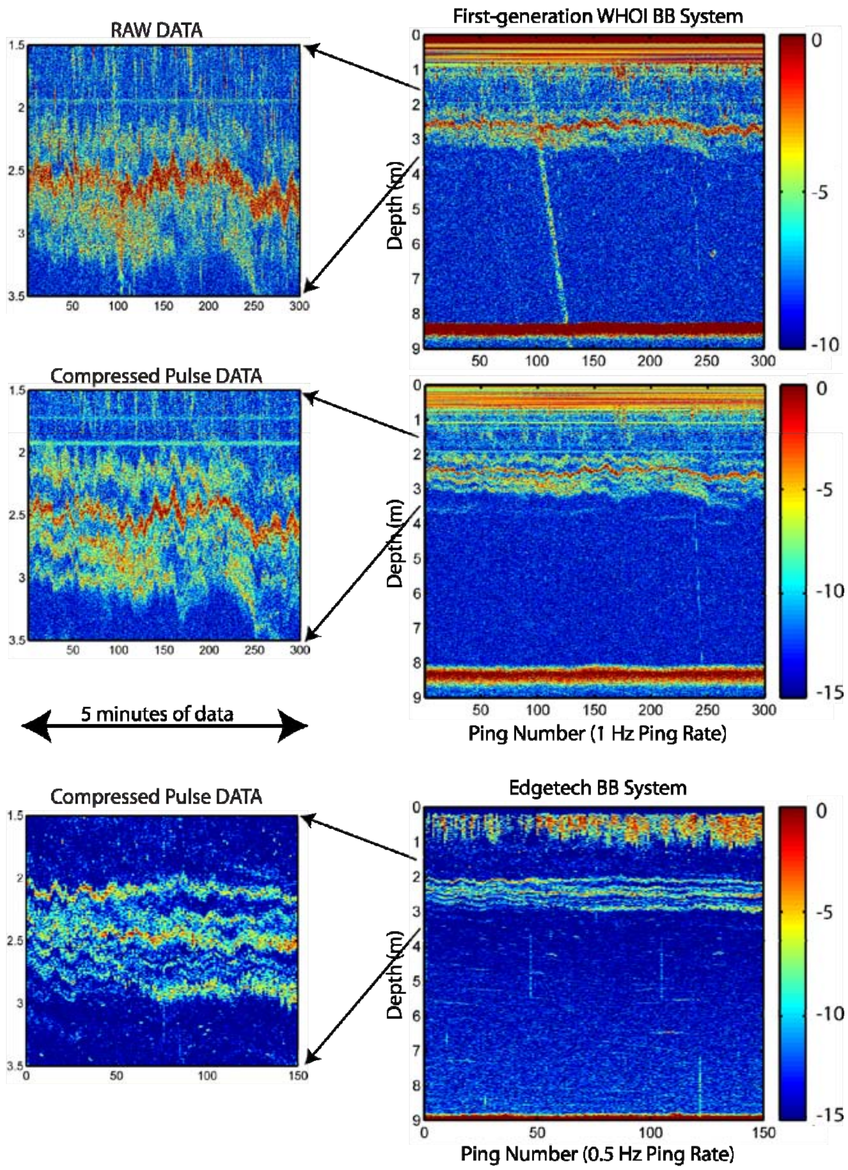

Figure 2. Top Panels: Broadband acoustic backscattering (amplitude of raw data) from salinity microstructure in the CT River in November 2008 using the 500 kHz BB channel of the first-generation WHOI broadband acoustic backscattering system. Middle Panels: Same as top panels but compressed pulse output instead of raw data. The transmit signal was 200μs in duration, corresponding to a pulse length of 30 cm. It can be seen that many thin scattering layers were observed, typically between 5 and 10cm thick. These layers are better resolved after pulse compression processing. In addition, after pulse compression processing, there is a signal-to-noise gain of approximately 5-7 dB. Bottom Panels: The Edgetech broadband system was also deployed during these field tests, providing a comparison for the WHOI broadband acoustic scattering system performance. The data shown here correspond to the compressed pulse output for the Edgetech 500 kHz BB channel. Though the data collected are not quite coincident, as the two instruments were deployed over the side at different locations, the data shown here were almost simultaneously collected, showing similar water column structure. In fact, the WHOI BB system has better horizontal resolution as it was pinging faster and the beamwidth of the WHOI 500 kHz BB channel is narrower than the Edgetech 500 kHz BB channel.